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A re-evaluation of the cloudiness factor in the Ångström and Penman equations for assessing short-wave and long-wave radiation exchanges at a surface

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Summary

On a monthly time-scale the equation derived by Penman for estimating net radiation at the earth's surface, using Campbell-Stokes sunshine duration data, appears to underestimate the net outgoing long-wave radiation. The operation of the Campbell-Stokes recorder as a radiation integrator under variously cloudy conditions is studied and, working on a daily basis, it is proposed that the term in the equation involving observed and theoretical maximum duration of bright sunshine be replaced by one which allows, in a physically realistic manner, for the unreliability of the sunshine recorder in cloudy weather. The arguments used are supported by data.

Introduction

In thermodynamic studies of a water body, the energy exchanges at the air–water interface must be specified — either from direct observation or, more commonly, calculated from readily available meteorological data. (To obviate this, some models, e.g. McCormick and Scavia (1981) use a known value of the water surface temperature T_s whilst others (e.g. Sundaram and Rehm, 1971; Noble, 1981) use the quasi-empirical concept of equilibrium temperature.) The surface energy balance (or budget) includes incoming short-wave (solar) radiation, outgoing and incoming long-wave radiation (from the atmosphere and clouds), energy fluxes associated with sensible and latent heat transfer, and specified values for reflectivities. (Except in extreme cases it can be safely assumed that the energy flux associated with precipitation can be considered to be negligible for the purposes of the present discussion.) The net

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Symbols

- a constant in Cowley equation = 0.29 (average value)
- a' constant in Ångström equation
- A_L long-wave reflectivity
- b constant in equations (3), (8) and (9)
- D maximum number of sunshine hours per day
- e_d vapour pressure (mb)
- e_{sa} saturated vapour pressure at temperature T_a
- n number of sunshine hours per day
- T_a air temperature
- T_s water surface temperature
- ϵ_a emissivity of atmosphere
- ϕ_0 net short-wave irradiance after reflection
- ϕ_∞ solar radiation at the top of the atmosphere
- ϕ_c sensible heat flux
- ϕ_d direct component of short-wave radiation
- ϕ_{dc} direct component of short-wave radiation under cloudless skies
- ϕ_e evaporative energy flux
- ϕ_L sum of non-radiative energy losses ($= \phi_e + \phi_c + \phi_{r2}$)
- ϕ_n net radiation
- ϕ_N net energy available
- ϕ_q net long-wave radiation lost ($= \phi_{r2} - \phi_{r1}$)
- ϕ_r atmospheric long-wave radiation received at surface (before reflection)
- ϕ_{r1} atmospheric long-wave radiative flux (after reflective losses)
- ϕ_{r2} long-wave radiative loss
- ϕ_s short-wave radiation incident at surface
- ψ latitude
- U relative humidity
- σ Stefan–Boltzmann constant ($=5.67 \times 10^{-8}$ W m^{-2} K^{-4})

radiation is then available to the water body either to heat up the surface layer or to be transported vertically downwards by turbulent diffusion or both. The application which motivated this work was a study of the thermal stratification cycles of lakes and reservoirs (wherein large-scale advection into or out of the water column can be neglected). Hence it is assumed that the total energy fluxes available to the water body will be the energy flux (per unit area) multiplied by the lake surface area. It is thus vital to quantify as accurately as possible all the energy terms which make up the surface energy balance. In this paper we show that recent data on the effects of clouds on evaluating short-wave radiative fluxes suggest that a modification should be made to the formulae previously used.

The surface energy budget

The total surface energy budget for a lake can be represented by the following equation:

$$\phi_0 + \phi_{r1} - \phi_L = \phi_N \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (1)$$

where ϕ_N is the net energy available, ϕ_0 is the net short-wave energy (i.e. after reflection), ϕ_{r1} the net incoming long-wave radiation and ϕ_L the sum of the energy losses given by

$$\phi_L = \phi_e + \phi_c + \phi_{r2} \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (2)$$

where ϕ_e is the evaporative energy flux, ϕ_c the sensible (convective) heat flux and ϕ_{r2} the long-wave (black body) radiative loss.

Some of the formulae for each of these terms are reviewed in Henderson-Sellers (1976, 1980). In particular we consider here the two formulae incorporating a cloudiness factor, viz. the Ångström (1920) formula for short-wave irradiation,

$$\phi_s/\phi_\infty = a' + b\, n/D, \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (3)$$

and the expression for atmospheric (long-wave) irradiance given either by (a):

$$\phi_r = \frac{\phi_{r1}}{(1 - A_L)} = \epsilon_a \sigma T_a^4, \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (4)$$

where ϵ_a is given graphically by Raphael (1962), data to which the curve

$$\epsilon_a = 0.688 + 0.125(1 - n/D) + 0.443 \times 10^{-4}\, U\, e_{sa} \qquad \ldots \quad (5)$$

has been fitted by Henderson-Sellers (1976), or (b) Penman's (1948) relation for net long-wave radiation lost ϕ_q $(= \phi_{r2} - \phi_{r1})$ (see e.g. Wales-Smith 1980) where,

$$\phi_q = \sigma T_a^4\,(0.56 - 0.08\sqrt{e_d})\,(0.10 + 0.90\, n/D). \qquad \ldots \quad (6)$$

Wales-Smith (1980) showed that 7-year average calendar-month estimates of net radiation calculated from meteorological data obtained at Kew and Eskdalemuir, using the equation which Penman (1948) derived from Ångström (1925) and Brunt (1932), are greater than comparable values of net radiation measured at the two locations. He showed, further, that the short-wave term in the equation gave very good estimates of average calendar-month global radiation measured at the two locations. In both comparisons the regression constants in the equation were derived from larger bodies of radiation and sunshine duration data than those used in the 7-year comparison.

He assumed, therefore, that the difference must be due to underestimation of net outgoing long-wave radiation (ϕ_q). This quantity is not measured directly at Meteorological Office establishments but indirect data may be obtained from measurements of net irradiation (ϕ_n) and global irradiation (ϕ_s) if an accepted value of the short-wave albedo of grass (0.25) is used in the equation

$$\phi_q = (1 - 0.25)\ \phi_s - \phi_n. \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (7)$$

He compared individual monthly values of the above quantity (for Kew, Eskdalemuir and Aldergrove) with corresponding values obtained from the long-wave term in the equation derived by

Penman (1948) and showed that the relationships at all three stations are similar. He then derived empirical, interim, monthly factors to adjust estimates of ϕ_q for operational use in a Meteorological Office (hydrometeorological) model.

Here we present observational and theoretical evidence that suggests that equation (6) underestimates ϕ_q as a consequence of the fact that values of n/D measured by a Campbell–Stokes sunshine recorder are on some occasions very poorly correlated with the incident irradiation (as measured by a solarimeter for example). It will be shown that in these cases an augmented value of n/D results in better agreement between calculated and observed values.

The Ångström equation

The Ångström equation (equation (3)) has been much discussed in the literature, especially by Glover and McCullough (1958) who identified a latitudinal variation in the coefficient a'. They recommend the equation

$$\phi_s/\phi_\infty = a \cos \psi + b\, n/D \quad \ldots \quad (8)$$

where ψ is the latitude and the coefficients are given as $a = 0.29$ and $b = 0.52$ valid over the latitude range 0° to 60°. Indeed it seems likely that this relationship is reasonably well satisfied for mean monthly values. Cowley (1978) solved a set of linear regression equations between daily global solar irradiation and duration of bright sunshine for ten stations in the United Kingdom which record both parameters. He found that the Ångström equation applied well to partially sunny days but that sunless days formed a separate population, often being associated with situations where multi-layered or thick clouds predominate, resulting in lower irradiation. Accordingly he adopted a modified equation

$$\phi_s/\phi_\infty = \delta\,\{a + b\,(n/D)\} + (1 - \delta)\, a' \quad \ldots \quad (9)$$

where δ is defined by ($\delta = 0$ if $n = 0$, $\delta = 1$ if $n > 0$), and

where a, b and a' all show a spatial variability. He presented annual average values of a and a' over the British Isles and values for b for June and December over Great Britain. However, results of a more recent experiment (discussed here) in Cornwall suggest that these relationships cannot be unique on a 'daily' basis since the effect of cloud type (not only amount) and cloud thickness can have a considerable effect on determining the degree of 'burn' of the card of a Campbell–Stokes recorder.

An underestimate of n/D by the Campbell–Stokes recorder causes the value of ϕ_q (from equation (6)) and to a lesser extent ϕ_s from equation (3) to be underestimates and it will be shown under what meteorological conditions this may occur. A suggested correction factor leads to an improved agreement between ϕ_q (calculated) and ϕ_q (observed) depicted graphically by Wales-Smith (1980) — see later discussion.

Experimental details and observational results

The study was undertaken over a two-month period (July to August 1980) at a site in St Austell in Cornwall ($\psi = 50.3°$N). Two instruments were used: the standard Kipp and Zonen solarimeter, which measures the energy flux by integrating the radiation distribution over a hemisphere, operating within the wavelength range of 0.3 – 2.5μm, and the Campbell–Stokes recorder which consists of a solid glass sphere seated within a bowl so that radiation from the sun is concentrated on a card. If the radiative flux is strong enough a burn mark will result and this is taken to represent the number of hours of sunshine, n.

Insolation

For all days during the study period a continuous trace was obtained from the solarimeter and compared with the 'burn' of a Campbell–Stokes recorder and the observed clouds (height, type and

thickness). Since it is evident that an equation of the form of equation (8) cannot be expected to give instantaneous values, comparisons are undertaken quantitatively by integrating the continuous trace by quadrature methods to derive total daily values of energy in J m^{-2}. Over the period of study this value was observed to be in the range 5.4×10^6 to 17.3×10^6 J m^{-2} per day. The data for the daily totals of observed irradiation, cloud cover and calculated values for ϕ, from equation (8) (at a latitude of 50.3°) are given in Table I.

On shorter time-scales (e.g. of minutes) the correlation is poorer. Indeed it may be these short time-scale non-correlations which are responsible for the poorly correlated points of the above two data sets. For example, it should be noted that on 8 and 22 August 1980 the daily insolation totals at St Austell were similar whereas the recorded sunshine amounts differed by a factor of 2. The present investigation aims to elucidate some possible causal mechanisms for such discrepancies.

Often the type of cloud, or its thickness, or its height — or some combination of all three — is readily demonstrated to be the controlling factor. For example, a total cover of high cirrus may well fail to prevent the radiation from being measured by the Campbell–Stokes recorder.

The records for 9 and 16 July display the effects of individual clouds. With thin white cirrus clouds obscuring the sun temporarily any drop in irradiance is very small (less than 200 W m^{-2}) and occurs with a less distinct rate of change than when the cloud is cumuliform. Lightly shadowed, white cumulus of medium thickness caused a decrease of 400 W m^{-2} to 500 W m^{-2} depending on its vertical extent, whilst a dark, heavily shadowed, thick cumulus cloud could cut out 700 W m^{-2} to 800 W m^{-2} (midday figures).

Table I. *Daily insolation values, observed and calculated*

Date August	Observed insolation (irradiation) (J m^{-2} × 10^6)	n/D	Calculated insolation (equation (8)) (J m^{-2} × 10^6)
7	5.982	0.020	6.922
8	13.106	0.290	11.891
10	5.249	0.041	7.301
15	12.893	0.470	15.207
22	13.010	0.612	17.807
25	14.043	0.396	13.843
26	17.360	0.825	21.731
27	9.415	0.182	9.895

Sunshine hours

On 'ideal' days with zero cloud (and hence maximum sunshine), the burn created by a Campbell–Stokes recorder would have smooth edges and a greatest thickness at noon, tapering off towards late evening and early morning. Fluctuations in the power received will cause a variation in the thickness of the burn and indeed at a certain energy level the absence of a burn altogether. It is generally assumed that the length of the burn gives a measure of the extent of sunshine, such that the absence of a burn is taken to be indicative of the presence of clouds obscuring the sun's disc.

However, a different situation arises with thick intermittent cumulus cloud. In these circumstances the length of period between two passing clouds controls whether a burn is achieved, since there appears to be a limit to the minimum duration of energy required to create a burn. On such days the drop in energy (of the order of 500 to 700 W m^{-2}), caused by the cloud passing between the sun and solarimeter, is sudden and this is shown by the way the burn stops at its previous thickness with no tapering or other effects. (There are good examples of these sharp breaks on 15 August, particularly at 0905 and 1245 GMT — see Fig. 1(a).) During hazy or extensive broken thin cloud the break in burn is more gradual with a slight tapering of thickness, as found at 1430 GMT on 25 August (Fig. 2).

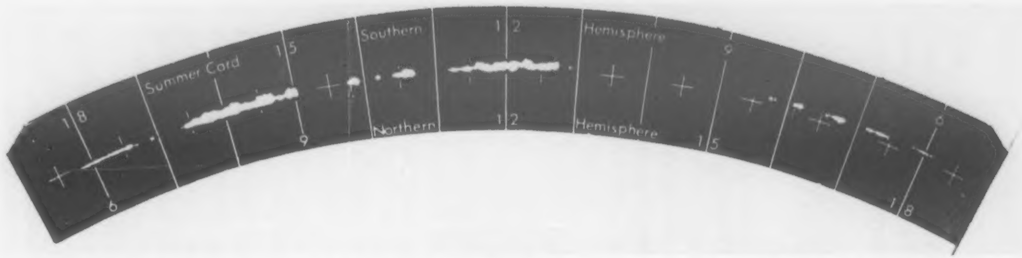

Figure 1(a). Campbell–Stokes 'burn' for 15 August 1980 illustrating sharp breaks caused by rapid passage of cumulus clouds.

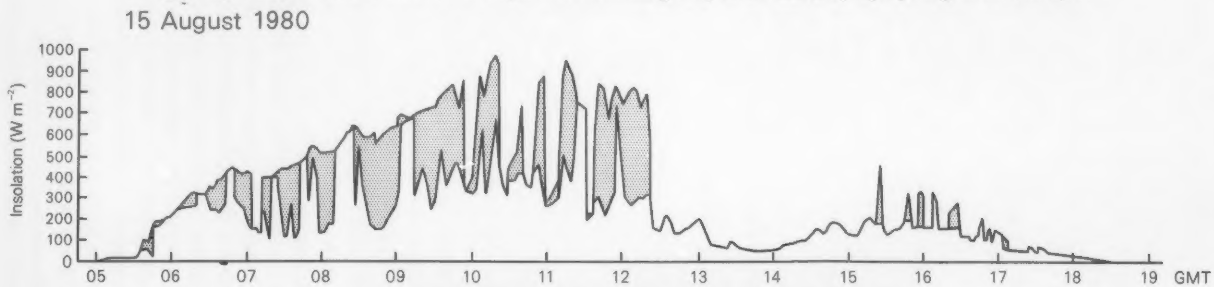

Figure 1(b). Envelopes of corresponding continuous trace for irradiance*.

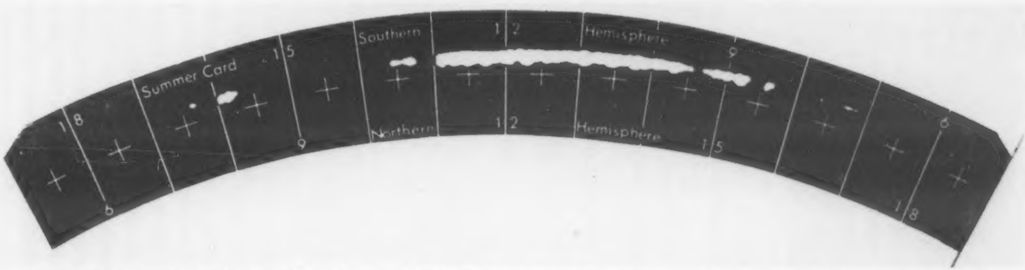

Figure 2(a). Campbell–Stokes 'burn' for 25 August 1980 illustrating tapering of burn resulting from breaks in extensive cloudy/ hazy conditions.

*The original traces often contained extremely rapid fluctuations impossible to reproduce; the printed figures show 'envelopes' between which such fluctuations occurred, with the area between these envelopes being stippled. Features in the original trace of duration five seconds or less have been smoothed out.

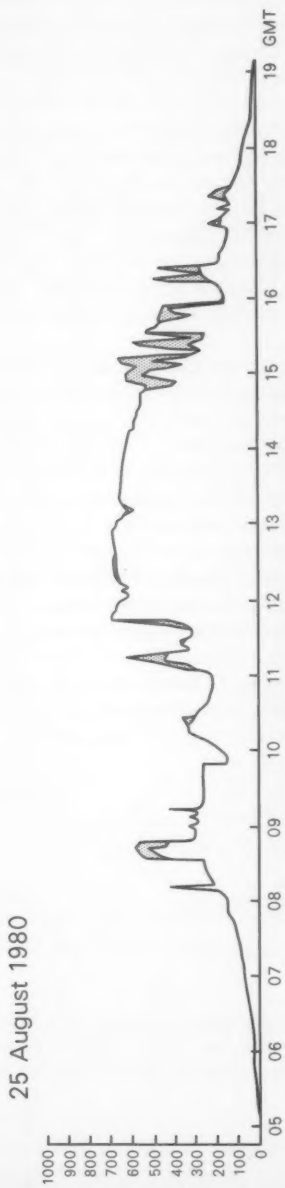

Figure 2(b). Envelopes of corresponding continuous trace for irradiance.

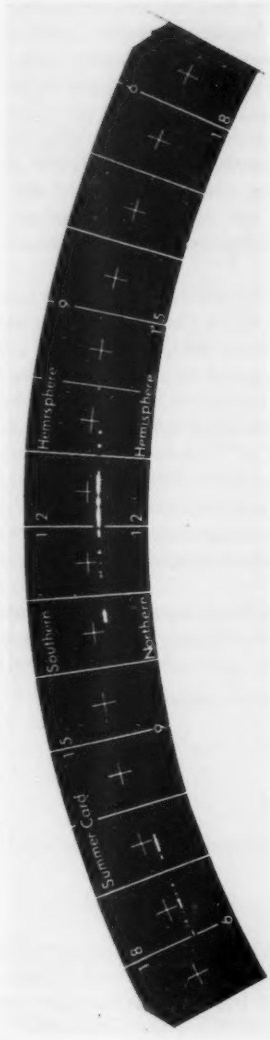

Figure 3(a). Campbell–Stokes 'burn' for 5 August 1980.

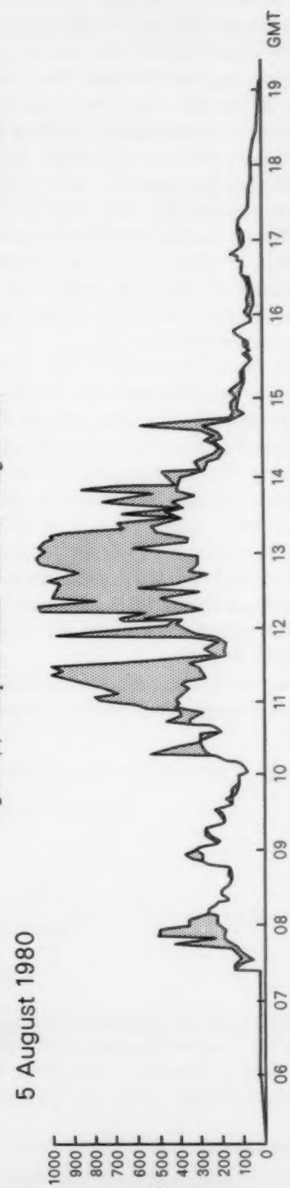

Figure 3(b). Envelopes of corresponding continuous trace for irradiance, illustrating the occurrence of high-intensity events of too limited duration to record a burn.

A study of 5, 8 and 22 August, all days of intermittent cumulus cloud and fine sunny spells, demonstrates the relative importance of period and amplitude for maxima of irradiance. As mentioned above, both 8 and 22 August recorded the same daily total of energy received but different sunshine hours on very similar days. The peaks on the 22nd are sharper than those on the 8th, rising and falling in 10 to 20 seconds. This means that the irradiance reaches a peak value more often than on the 8th, thus allowing it to maintain its burning influence on the sunshine card. On 5 August, a day when many peaks lasted for only 5 to 10 seconds, it was found that the duration of the peaks was more important than amplitude. For example, some peaks as high as 1000 W m^{-2} were of too limited duration to create an impression on the card and the trace was ephemeral (Fig. 3), despite hot, intermittently sunny conditions. In such conditions it is suggested that the 'overburn', noted by Suckling and Hay (1977) and by Painter (1981), may be instead an under-recording of the irradiation either because of slow instrumental response times or by the sampling procedure (e.g. Painter (1981) assumed the instantaneous value every minute to be representative of these continuous data — clearly not the case in the example outlined above).

The minimum value of the power required to create a burn appears to vary with the time of day (a factor not incorporated into the design of the Campbell–Stokes sunshine recorder). Brooks and Brooks (1947) note that the sun must be 5° above the horizon before a burn is recorded. This present study suggests that noon values of energy required for a burn tend to be higher than those in the evening and morning. For example, during the period between 0900 and 0930 GMT on 27 August, a sunshine burn was recorded with minimum energy values of 250 W m^{-2}. However, during the period between 1100 and 1200 GMT a minimum level of 350 W m^{-2} was obtained but relatively little sunshine (less than half an hour) recorded. On 15 August at and just before 1800 GMT sunshine is recorded when the isolation trace is always below 200 W m^{-2}. However, at 1100 GMT minimum values were as much as 300 W m^{-2} and at 1300 GMT 200 W m^{-2}, both with no corresponding sunshine. This is in good general agreement with Painter (1981) who found the threshold irradiance required to produce a burn varied in the range 106–285 W m^{-2}.

Another method of relating net insolation to sunshine burns is to correlate the burn width with a value of solar energy. The best day to study was 26 August as it had the most nearly continuous burn. Table II shows the values obtained on both 26 and 22 August. Certainly a linear relationship is suggested. Table III gives insolation values and burn widths for Akrotiri, Cyprus, during June 1981. Again a linear relationship between burn width and irradiance is strongly suggested. Further data collection to substantiate and verify any such relationship is recommended.

Table II. *Relation between sunshine burn width and irradiance.*

Sunshine burn width	Irradiance (W m^{-2})	Conditions
26 August		
2 mm	150	Evening
3 mm	600	Midday haze
22 August		
5 mm	1000	Midday peaks

Discussion

Our observations show that in cases of intermittent thick cumulus cloud which obscures the sun's disc such that the periods between observations may be small, a sunshine burn may not be recorded even

Table III. *Numbers of cases corresponding to 60-minute sunshine burn.*

Intensity of global irradiance is continuously indicated (as voltage) in the meteorological office at Akrotiri, Cyprus (34°35′N). The table shows the variation of irradiance intensity (mV), measured at the beginning of each clock hour corresponding to a 60-minute Campbell–Stokes recorder burn during the succeeding hour in June 1981.

	Global irradiance intensity (mV)											
Local time (GMT + 2h)	2.0 to 2.9	3.0 to 3.9	4.0 to 4.9	5.0 to 5.9	6.0 to 6.9	7.0 to 7.9	8.0 to 8.9	9.0 to 9.9	10.0 to 10.9	11.0 to 11.9	12.0 to 12.9	Typical burn width (mm)
0600	24											1.0
0700			25	2								1.1
0800					17	10						1.2
0900						1	22	7				1.4
1000								3	26			1.6
1100									7	22	1	1.8
1200									4	25	1	2.0
1300								1	22	6		1.8
1400						1	1	23	4			1.6
1500				1		13	16					1.4
1600		1		13	14							1.2
1700	1	23	5									1.1

(1.125 mV is equivalent to 100 W m^{-2})

when incident radiation values are high. In an extreme case (5 August, cf. 22 August) it has been observed that the Campbell–Stokes evaluation of n/D may result in an underestimate of the incident radiation by a factor of 0.65 (corresponding to an underestimate of n/D by a factor of 0.44, i.e less than half the hours of sunshine were recorded).

In less extreme cases it is possible that an underestimate by about 10–15% may occur frequently. Here we take a numerical example to compare the data of Wales-Smith (1980), the Penman (1948) equations, and the direct solar radiation model of Suckling and Hay (1977).

Example

True values: $n/D = 0.35$ $\quad 1-n/D = n_c = 0.65$

Observed say $n/D = 0.30$ $\quad n_c = 0.70$

In this case the estimate of ϕ_s from Ångström's equation (equation (8)) is replaced by a new estimate ϕ_s' given as (UK latitudes);

$$\phi_s' = \phi_s \frac{0.18 + 0.55 \times 0.35}{0.18 + 0.55 \times 0.30} = 1.08\,\phi_s$$

However, a much greater effect is seen in the calculation of ϕ_q (equation (6)). Here ϕ_q is replaced by ϕ_q':

$$\phi_q' = \phi_q \frac{0.10 + 0.9 \times 0.35}{0.10 + 0.9 \times 0.30} = 1.12\,\phi_q$$

As this phenomenon can be considered to be restricted to the summer months (UK) when convective cloud formation occurs as a result of enhanced irradiation, this suggests that Wales-Smith's ratio of ϕ_q(measured)/ϕ_q (predicted by equation (6)) in Fig. 4 should be multiplied by a conversion factor of

about 1/1.12 in the summer months (see solid curve in Fig. 4); suggesting that the Ångström and Penman approach is acceptable when the factor n/D is correctly estimated in this way.

One modelling solution to this has been presented by Suckling and Hay (1977) (although their total cloud model does not appear to be simple enough for daily use unless a wide data base is available). They acknowledge the problems of unreliability of the sunshine recorder and use a parameter n_e to measure an effective cloud amount. This is given by

$$n_e = \frac{n_c A + B\,(1-n/D)}{A+B}, \qquad (10)$$

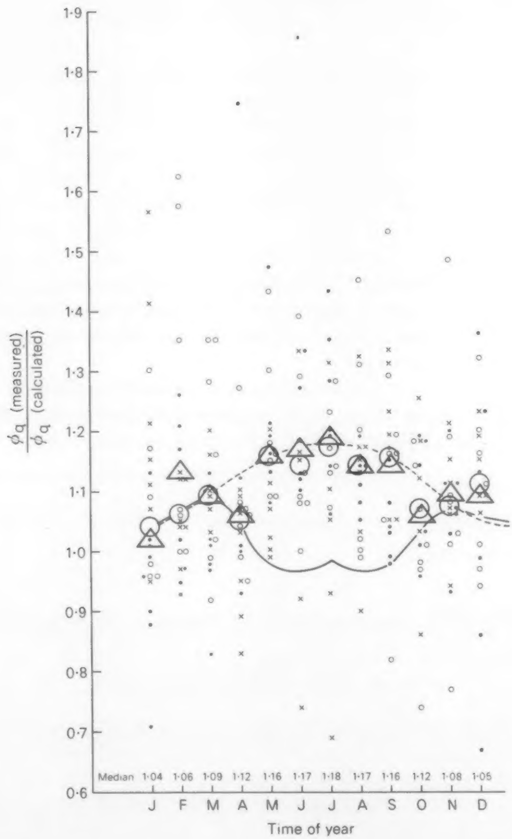

Figure 4. Values of ϕ_q (measured)/ ϕ_q (calculated) for three stations: Kew (.), Eskdalemuir (o) and Aldergrove (x) (means (△), medians (○)), after Wales-Smith (1980) together with suggested corrected curve (solid line).

where A and B are chosen empirically. This is designed to modify the incoming solar radiation Φ_∞ to give the *direct* component ϕ_d from

$$\phi_d' = \phi_{dc}(1-n_e) \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (11)$$

(where ϕ_{dc} is the cloudless sky value of ϕ_d).
For the numerical values given here in comparison with the simpler calculation of

$$\phi_d = \phi_{dc}\, n/D \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (12)$$

it is found that

$$\phi_d' = \phi_d \times \frac{(1 - \tfrac{1}{2}(0.65 + 0.70))}{0.30} = 1.08\,\phi_d.$$

Alternatively, using this value of n_e to replace the factor $1-n/D$ in the Ångström equation gives a correction factor (with A=B=1) of

$$\phi_s' = \phi_s \frac{0.18 + 0.55 \times (1-0.675)}{0.18 + 0.55 \times 0.30} = 1.04\,\phi_s.$$

It can thus be concluded that the effective cloudiness factor of Suckling and Hay (1977) does seem to compensate adequately for the unreliability of the sunshine record under conditions of intermittent cumulus clouds as described here.

We therefore suggest that the Penman formulations used in Wales-Smith (1980) are better estimates of ϕ_s and ϕ_q when n/D is replaced by $1-n_e$ where n_e is given by equation (10) which uses observed sunshine amounts and observed cloud amounts — both factors which have been measured over long (historical) periods.

For lake studies, these equations are useful for calculating the net heat stored in the water. During periods of extreme convective activity, we advocate the use of n_e in place of n. Hence observations are required not only of sunshine hours but also of cloud amount (neither of which is difficult to obtain in general).

References

Ångström, A. 1925 On radiation and climate. *Geogr Ann* 122–142.

Brooks, C. F. and Brooks, E. S. 1947 Sunshine recorders: A comparative study of the burning glass and thermometric systems. *J Meteorol*, **4**, 105–115.

Brunt, D. 1932 Notes on radiation in the atmosphere. I. *Q J R Meteorol Soc*, **58**, 389–420.

Cowley, J. P. 1978 The distribution over Great Britain of global solar irradiation on a horizontal surface. *Meteorol Mag*, **107**, 357–373.

Glover, J. and McCulloch, J. S. G. 1958 The empirical relation between solar radiation and hours of sunshine. *Q J R Meteorol Soc*, **84**, 172–175.

Henderson-Sellers, B. 1976 Time dependent transport mechanisms in freshwater lakes. (Unpublished Ph.D. thesis, University of Leicester.)

1980 Limnological modelling: simulation of vertical profiles of temperature, dissolved oxygen and nutrients. I. Theory. *J Limnol Soc S Afr*, **6**, 49–54.

McCormick, M. J. and Scavia, D. 1981 Calculation of vertical profiles of lake-averaged temperature and diffusivity in Lakes Ontario and Washington. *Water Resour Res*, **17**, 305–310.

Noble, R. D. 1981 Comparison of two surface heat exchange models. *Proc Am Soc Civ Eng, J Hydraul Div*, **107** (HY3), 361–366.

Painter, H. E. 1981 The performance of a Campbell-Stokes sunshine recorder compared with a simultaneous record of the normal incidence irradiance. *Meteorol Mag*, **110**, 102–109.

Penman, H. L. 1948 Natural evaporation from open water, bare soil and grass. *Proc R Soc*, A, **193**, 120–145.

Raphael, J. M. 1962 Prediction of temperature in rivers and reservoirs. *Proc Am Soc Civ Eng, J Port Div*, **88** (PO2), 157–181.

Suckling P. W. and Hay, J. E. 1977 A cloud layer-sunshine model for estimating direct, diffuse and total solar radiation. *Atmos*, **15**, 194–207.

Sundaram, T. R. and Rehm, R. G. 1971 Formation and maintenance of thermoclines in temperate lakes. *Am Inst Aeronaut Astronaut J*, **9**, 1322–1330.

Wales-Smith, B. G. 1980 Estimates of net radiation for evaporation calculations. *Int Assoc Hydrol Sci, Hydrol Sci Bull*, **25**, 237–242.

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A cloud-like land feature in satellite imagery of Saudi Arabia

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Summary

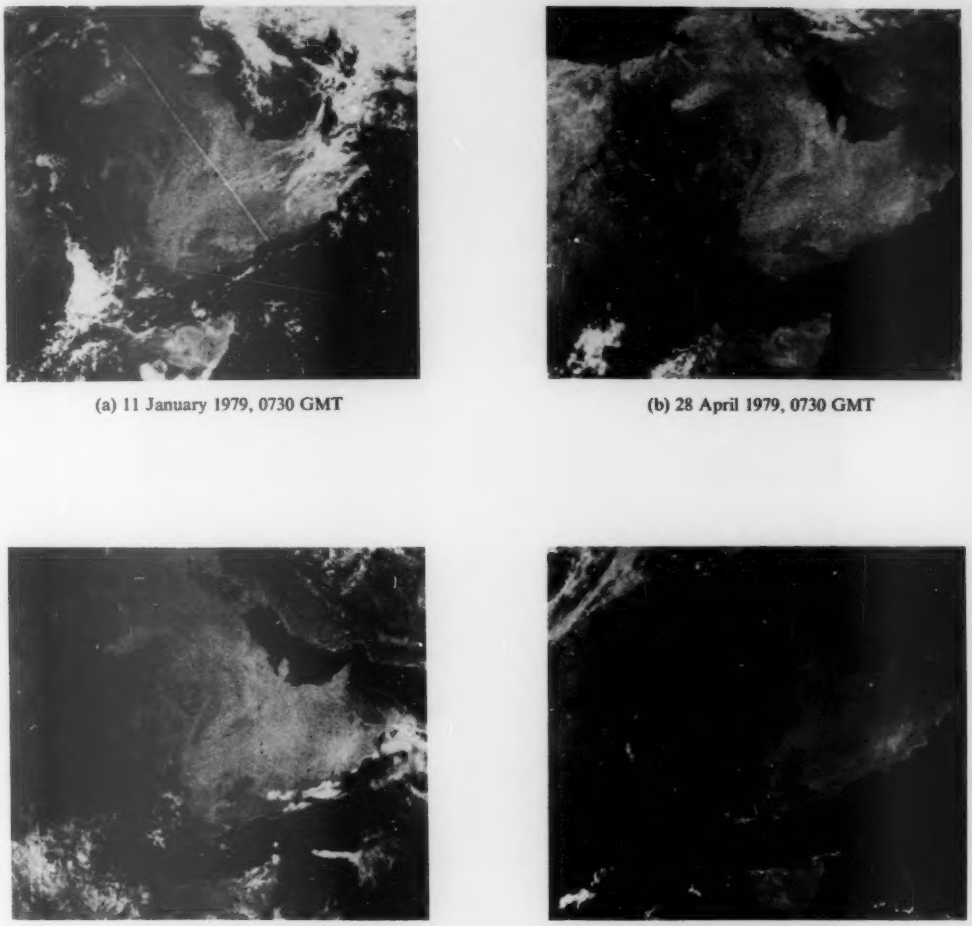
A cloud-like feature regularly appearing in satellite photographs of the Arabian Peninsula is demonstrated to be the Great Nafud Desert which is covered with highly reflecting sand.

Viewers of meteorological satellite imagery of the Arabian Peninsula are sometimes deceived by an apparent cloud in north-western Saudi Arabia, which is actually a terrain feature.

The feature is shown in Fig. 1, in a visible-band image for each of the four seasons of the year 1979 (images from the GOES satellite deployed at 58°E during FGGE). The 'cloud' feature appears just south and substantially east of the south tip of the Sinai Peninsula. The location and shape of the feature are constant through the year, while the reflectivity is essentially so.

Fig. 2 is a typical Meteosat image of the same area. The persistent feature is less bright than the cumuliform complexes to its south, but about as bright as the cirrus shield above the convective clouds.

Fig. 3 shows the feature as imaged by NOAA-7. At the higher resolution of the AVHRR (Advanced Very High Resolution Radiometer) system, greater detail, including tonal gradients within the cloud-like feature, are evident.



(a) 11 January 1979, 0730 GMT

(b) 28 April 1979, 0730 GMT

(c) 8 July 1979, 0430 GMT

(d) 6 November 1979, 0730 GMT

Figure 1. GOES (I0) views of the Arabian Peninsula in the visible band. The persistence of the cloud-like feature in north-west Saudi Arabia throughout the year indicates the feature to be permanent and not a result of vegetative or other temporal tonal variations.

Figure 2. Typical Meteosat visible image showing the stationary 'cloud'.

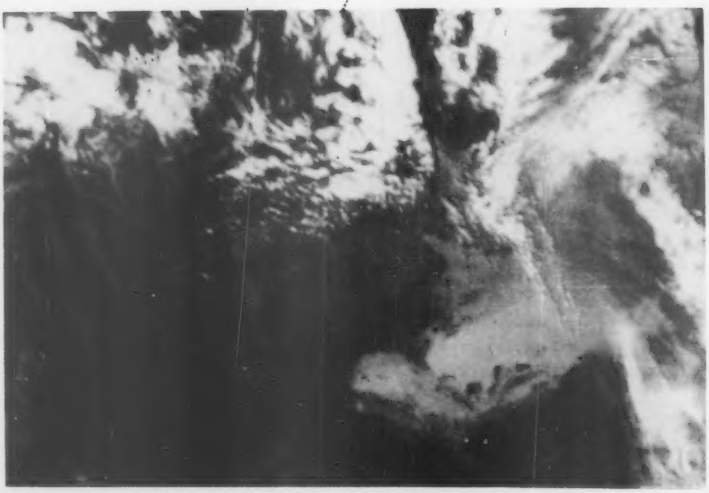


Figure 3. NOAA-7 Channel 2 (0.725–1.10μm) AVHRR view, 13 March 1982, 1146 GMT. At this higher resolution the 'cloud' resembles the head of a snarling dog or wolf.

The feature under discussion is occasionally apparent (as a very small tonal contrast) in infra-red images at night. This implies variations in land surface that influence nocturnal radiational properties.

Fig. 4 shows the landforms of Saudi Arabia and adequately identifies the persistent 'cloud' as the Great Nafud Desert. Note the similarity in shape of the Desert shown here with the shape shown in Fig. 3. Resemblance to a canine head is suggested in both.

This aspect is also evident in Fig. 5, from a LANDSAT image that has been enhanced to accentuate topographic detail. Fig. 6, a close-up photograph of a portion of Fig. 5 (junction of the canine's left ear and head), dramatically shows the differences in sand surface texture, which presumably result in the bogus cloud.

It is to be noted that the Great Nafud 'cloud', for reasons as yet unknown to us, appears to be more highly reflective than the much larger, and equally barren, Empty Quarter Desert (Ar Rub Al Khali in Fig. 4) in south-east Saudi Arabia. The higher contrast of the former may be due to the terrain of igneous origin that borders the western Great Nafud (Ferguson, personal communication).

Figure 4. Landforms of Saudi Arabia (Bindagji 1980). The cloud-like feature in Figs 1–3 is co-located with the desert identified as the Great Nafud.

Acknowledgements

We express our appreciation to NOAA-NESS for GOES imagery, to Mr H. H. Bindagji for authorizing reproduction of Fig. 4 from his *Atlas of Saudi Arabia* (Oxford University Press, 1980), and to Mr K. P. Ferguson Jr, Remote Sensing Specialist, US Geological Survey, Saudi Arabian Mission, for access to the LANDSAT image copied in Fig. 5.

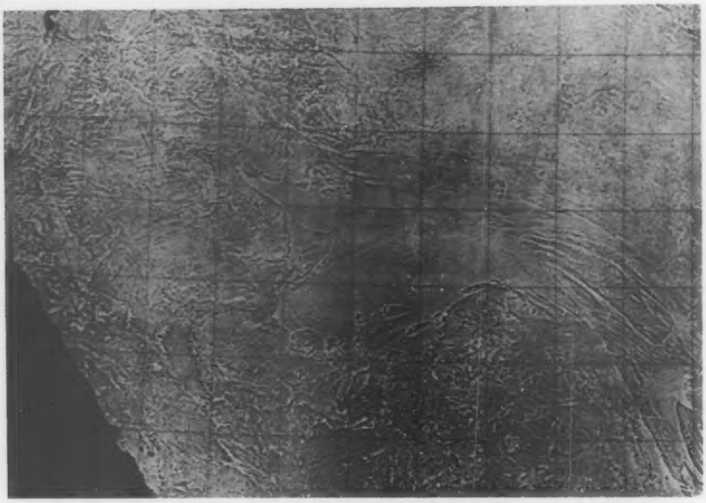


Figure 5. The Great Nafud as depicted on a 1:2 000 000 scale mosaic of the Arabian Peninsula. The mosaic is derived from LANDSAT high-pass filter, Band 7 imagery enhanced to emphasize topographic details. (US Geological Survey, Saudi Arabian Mission, 1979)

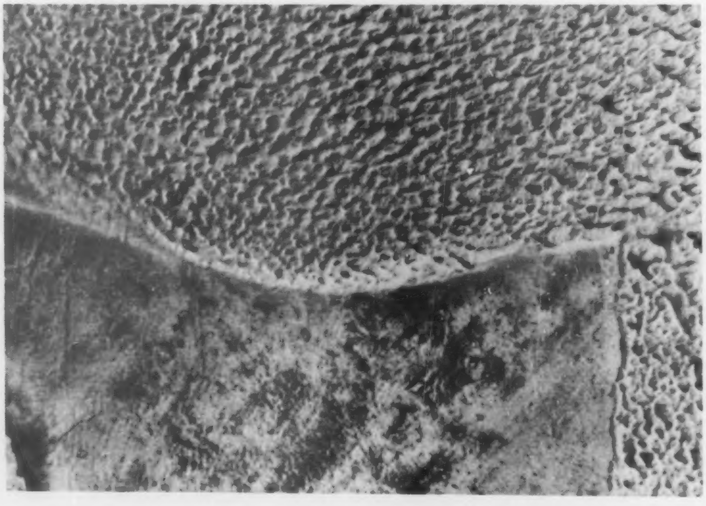


Figure 6. Close-up photograph of a portion of Fig. 5, showing the change in sand texture resulting in the cloud-like appearance of the Great Nafud Desert.

Awards

L. G. Groves Memorial Prizes and Awards

The first award of prizes for two years took place on Monday 15 November 1982 at the Main Building, Ministry of Defence, Whitehall. The Vice Chief of the Air Staff (Air Marshal P. R. Harding, C. B.) presided, and the Inspector of Flight Safety, RAF (Air Commodore T. H. Stonor) read the citations.

Air Marshal Harding introduced the proceedings and explained that the 1981 prizes and awards were the last to be given under the old arrangements. In 1983, as a result of further generous bequests made by the late Mrs Dorothy Groves, it was hoped to enlarge the scope of the awards to include, for example, teams as well as individuals. He offered his congratulations to the present winners and called on Mr Nicholas Abbott, as representative of the Groves family, to present the prizes.

Mr Abbott, in his opening remarks, thanked everyone who had been concerned with making the arrangements for the ceremony; he then presented the winners with their prizes and certificates, adding his own personal congratulations.

L. G. Groves Memorial Prize and Award winners with Mr Nicholas Abbott, Air Marshal P. R. Harding and Air Commodore T. H. Stonor, Seated, left to right: Mr Nicholas Abbott, Air Marshal P. R. Harding, C. B., and Air Commodore T. H. Stonor. Standing, left to right: Flight Lieutenant P. J. Bennett, Corporal S. G. Yates, Mrs E. C. Squires and Dr P. Ryder.

The 1981 Aircraft Safety Prize was awarded to Flight Lieutenant P. J. Bennett of the Royal Aircraft Establishment, Bedford for his paper introducing a modified head-up display of power margin in Harrier and AV-8 aircraft. The citation was as follows:

'The paper describes a head-up display symbol which presents the power margin available in a simple and easily assimilated form. Pilots of Harrier aircraft are vitally concerned with power margin, particularly in the hover, yet here the workload is high and to ensure safe and correct flight the pilot must devote much of his attention to outside visual cues. Flight Lieutenant Bennett's idea decreases the pilot workload during this critical stage of flying by enabling important engine parameters to be assimilated without having to refocus the eyes and look at head-down display. The new head-up display uses inputs of jet pipe temperature and engine speed to display the excess power available in a simple analogue form. It has been extensively evaluated in flight and has been found to reduce workload significantly. The modification is inexpensive and is being actively pursued by staffs in both the UK and USA.'

Flight Lieutenant P. J. Bennett, winner of the Aircraft Safety Prize, receives his citation from Mr Nicholas Abbott. In the background is his prize — a painting of the RAE Bedford Harrier aircraft by aviation artist Mr Chris Golds.

Dr P. Ryder, winner of the Meteorology Prize, with Mr Nicholas Abbott and Air Marshal P. R. Harding.

The 1981 Meteorology Prize was awarded to Dr P. Ryder, now Head of the Systems Development Branch of the Meteorological Office, for his work on cloud physics with the following citation:

'Dr P. Ryder has made major contributions to research in cloud physics. In recent years he developed a system for studying the large-scale structure and dynamics of cloud systems by means of dropsondes released from the Meteorological Research Flight C-130 aircraft. These sondes can be tracked automatically from the aircraft, providing high precision wind profiles. Sensors on the sondes telemeter data on temperature, humidity and pressure back to the aircraft. As Head of the Cloud Physics Branch from 1976 to 1982, Dr Ryder gave strong leadership to his research team. He guided design and development of cloud microphysics instrumentation on the C-130. He also fostered theoretical work so that experiments using these facilities could be designed to test and extend our understanding of the role of physical processes in clouds. His analysis of the meteorological factors in helicopter icing problems was typical of an ability to apply deep understanding of physical processes to operational problems.'

The Meteorological Observer's Award for 1981 was made to Mrs E. C. Squires of the Meteorological Research Flight, Royal Aircraft Establishment, Farnborough with the following citation:

'Mrs Squires joined the Meteorological Research Flight in January 1978 and has been employed in a variety of research support roles. A major part of her work has been as a flight test observer in the Hercules C-130 and the Canberra (before it was withdrawn in 1981) and more recently in the role of Flight Leader. In all of these tasks she has earned the respect of the RAF aircrew as well as of her scientific colleagues, not only for her undoubted expertise and competence in the flying roles but also for her unbounded enthusiasm for her work in the air and on the ground. She has made, and continues to make, a most valuable contribution to the MRF research program.'

It is worth noting that Mrs Squires is the first woman to gain one of the Groves Memorial Prizes or Awards, and we offer her our especial congratulations.

Mrs E. C. Squires, winner of the Meteorological Observer's Award. Mr Nicholas Abbott and Air Marshal P. R. Harding admire her prize — a reproduction of the Admiral's Barometer designed by Robert FitzRoy who commanded HMS *Beagle* on Darwin's famous voyage.

Mr Nicholas Abbott congratulates Corporal S. G. Yates, winner of the Second Memorial Award.

The 1981 Second Memorial Award was made to Corporal S. G. Yates, Air Traffic Control Section, RAF Binbrook, Lincolnshire, in recognition of his originating a booklet entitled 'Last Look Checks' for use by runway controllers. The booklet has now been issued by Strike Command and it is now in daily use as a timely reminder to the operating staff. The citation is as follows:

'An important task undertaken by runway controllers is to scrutinize each aircraft carefully as it lines up for take-off to ensure, as far as can be determined, that it does not get airborne with some defect which has gone unnoticed. At stations which do not have runway controllers, Air Traffic Control (ATC) staff may be able to perform the same function from the tower. In order to perform this particular task properly, ATC staff, and where they are established, runway controllers, must be familiar with the home-based aircraft but it will be less easy to become sufficiently familiar with aircraft from other units, particularly aircraft that visit infrequently.

'Corporal S. G. Yates originated a series of diagrams to enable all ATC staff to familiarize themselves with the relevant features of RAF aircraft they are likely to encounter. The diagrams show the location of blanks, pins, plugs and locks which should be removed before take-off, specific panels which should be checked for security and those areas where fuel venting may be expected.'

Notes and news

50 years ago

The following extract is taken from the *Meteorological Magazine*, March 1933, **68**, 31–35.

The Great Snowstorms of February, 1933

CONTRIBUTED BY THE FORECAST DIVISION, METEOROLOGICAL OFFICE

A series of intense and prolonged snowstorms, one of the worst within living memory, occurred in most districts of the British Isles during the period Thursday, February 23rd to Sunday, February 26th, 1933, and it is proposed to give a preliminary account of the storms and of their meteorological aspects.

According to the daily Press the storms were the worst experienced since the well-known snowstorms of January 17th–21st, 1881.

[Here followed a detailed discussion of the synoptic situation and the forecasts that were issued.]

The main storm commenced in Ireland and Wales on the evening of the 23rd, and was continuous for more than 24 hours over the greater part of both countries (with the exception of the north) and drifted in an easterly wind which increased to gale force. During the night of the 23rd a rainfall equivalent of 1.69in. fell at Pembroke. Over a considerable area in south Wales the level fall probably reached or exceeded two feet. Many villages were isolated, and railway traffic was badly delayed, the Irish Mail from Fishguard arriving at Paddington 13 hours late. Many telegraph wires were broken down by the weight of snow, and photographs in the Press showed the wet nature of the snow near the south coast of Wales. In Wales and Ireland the statements in the Press that the storm was the worst for 50 years were quite probably justified. A letter from Hacketstown Rectory, Co. Carlow, reports a "record" snowfall with numerous 6- to 10-foot drifts. Over most of southern England the storm was less severe than that of December, 1927. It was, however, severe over a large area in the south-west, though on the south coast only sleet and rain were reported. During the 24th the storm spread eastward, and then extended

northward slightly beyond the Scottish border, and included northern Ireland. A fair degree of severity was maintained in the Midlands and north, and trains were delayed by heavy drifting, which was helped by the fact that the temperature was still below the freezing point. Towards the east the severity of the storm fell off rapidly, and the east coast had little snow. In London there was a moderate fall which lay on open spaces, but had almost disappeared by next morning.

On the 25th and 26th there was sleet and rain in the south, but further considerable snowfall in many other districts. The change from rain and sleet to snow took place surprisingly far south, considering the strength of the south-easterly wind. It was not only a question of height above sea level, since snow fell on low ground also, for example at Ross-on-Wye at 7h. on the 26th, and also at Cranwell, where 8 inches were lying. At 13h. on that day it was still snowing at Birmingham. No doubt the air at low levels was quickly cooled as it penetrated inland, both by the snow on the ground and by snow falling into the surface layer from above.

In Yorkshire the fall was heavy and continued until the evening of the 26th, when no less than 28 inches were lying at Harrogate. Conditions were already severe in this region before the main storm, and the total snowfall was probably as heavy as in south Wales. A number of villages were isolated in Yorkshire and Derbyshire. At Buxton the average depth was estimated to be fully two feet.

The Snowstorm in Breconshire

The snowfall here on February 24th was a record for more than 20 years. All roads were completely impassable to traffic. Towns in the hills had huge drifts 10 and 14ft deep in places. I registered 1.61 inch in the rain-gauge — the snow was 18 inches on the level in the valley. I was up on the mountains all that morning with local farmers looking for sheep and, although I am about in all weathers, never remember anything like the conditions. The wind was terrific and the drift absolutely choking — it was so bad that one could only see about 20 yards and we were forced to shelter in the rocks on the way down as one couldn't face the drift without choking. I estimated the wind on the summit of the mountain as about Force 9, in the valley only Force 7. All the sheep were smothered and we had to leave them and shelter ourselves. We were almost snowed up when we ventured back, the drifts being 16 feet in the hollows, and it took us nearly 4½ hours to go three miles. I think we were lucky to get back.

R. G. SANDEMAN.

Dan-y-Parc, Crickhowell, Breconshire. March 2nd, 1933.

Obituary

We regret to record the death on 10 September 1982 of Mr A. R. Parry, Assistant Scientific Officer, of the Synoptic Climatology Branch. Arthur Parry joined the Office in 1947 after service in the Army and the RAF Meteorological Branch. For the next 20 years he worked at various forecasting outstations including Prestwick, Rheindalen and Shawbury. In 1967 he was posted to Headquarters and worked in the Central Forecasting, Observational Requirements and Practices, and Boundary Layer Branches before joining the Synoptic Climatology Branch in October 1981.

Arthur Parry had an amiable and helpful personality, and got on well with his colleagues. During part of the time that he was at Headquarters he played the drums for the Bracknell Brass Band and also helped with a local Cub Pack.

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NOTICES

It is requested that all books for review and communications for the Editor be addressed to the Director-General, Meteorological Office, London Road, Bracknell RG12 2SZ and marked 'For Meteorological Magazine'.

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